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A review on electricity generation based on biomass residue in Malaysia

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ABSTRACT

Nowadays, biomass is considered as one of the main sources of energy for both developed and developing countries. Malaysia with a large amount of biomass residues as a source of electricity generation is considered as one of the potential countries in this field. This study aims to analyze the potential of recovering energy from major source of biomass residue in Malaysia. For this purpose, the agricultural crop residues and industrial crop waste are investigated. These will contribute substantially to harness a sustainable resource management system in Malaysia to reduce the major disposal problem of biomass residue. The effective use of the waste can supply the required fuel for future electricity generation.

Contents

1. Introduction

It is becoming increasingly difficult to ignore the global warming and the effects of fossil fuels and it is observing as one of the major concerns around the world [1–3]. The limitations of fossil fuel sources motivate the government to shift the energy policy towards the other source of energy. Besides the problem of fossil fuels diminution, issues on energy security and environment concerns lead the societies to utilize various sources of energy [4]. Nowadays, renewable energy sources are one of the most widely used sources instead of the conventional energy sources. There are different policies around the world which take

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Table 1
The electricity generation based on renewable sources of different regions(GW h).

Region	Municipal waste	Industrial waste	Solid waste	Biogas	Liquid biofuel	Geothermal	Solar thermal	Hydro	Solar PV	Tidal/wave/ocean	Wind
ASEAN	0	0	4,801	39	0	19,022	0	66,003	5	0	61
Non OECD	2984	2,587	40,745	196	0	23,654	0	1906,363	247	0	30,596
OECD	55,136	8,620	122,080	31,239	3443	40,594	898	1381,191	11,769	546	187,908
World	58,120	11,207	162,825	31,435	3443	64,608	898	3287,554	12,061	546	218,504

the renewable sources into account [5–10]. For example, in 2009, China brought its total renewable capacity to 226 GW by adding 37 GW of renewable energy [11]. In 2008, Germany's primary renewable energy consumption was around 7.3% and it is predicted to be equal to 33% by 2020 [12]. The projection of world energy consumption is predicted to increase by 49% from 2007 to 2035 [13]. The electricity generation based on renewable sources of different regions in 2008 is summarized in Table 1 [14]. The ratio of energy consumption to renewable energy production in ASEAN countries is around 1.19%, whilst it is 41.03% for OECD. ASEAN countries are still too much reliance on fossil fuels to generate energy. In 2009, almost 94.5% of electricity in Malaysia was generated by using fossil fuels such as natural gas, coal and oil [15]. Although Malaysia has several renewable energy sources like biomass, solar, hydropower and wind, it is still dependent of fossil fuels [16–20]. Among all the renewable sources biomass has the highest potential to be utilized as the source of renewable energy [21]. Therefore, this study focuses on the analysis of potential recovering energy from biomass residue in Malaysia based on the agricultural and plantation residue in Malaysia.

2. Malaysia energy scenario

During the recent years, the demand of electricity was increased in line with the world population and economic growth in developing countries [22–30]. Malaysian electricity generation in 2009 was reported to be around 21,817 MW that shows around 10.6% increase in comparison with this amount in 2008 [31]. Generally, there is a direct relation between the energy usage and pollutant that have a negative impact to environment [32–36]. A considerable number of literatures have been published on the effect of fossil fuel combustion for electricity generation, on the extreme changes in global climate [37–44]. The combustion of fossil fuel contributes as the most significant source of atmospheric CO_2 production. Other greenhouse gases(CH_4, N_2O, O_3) contribute to climate change through the so called global warming effect, but their cumulative effect is estimated to be at least one order of magnitude lower than that of CO_2 [45]. According to Ref. [46], the emission of greenhouse gases is predicted to increase from 43 Mt in 2005 to 110 Mt by 2020. Due to climate variability in Malaysia, the average temperature increased by 0.5 °C to 1.5 °C in the Peninsular Malaysia and 0.5 °C to 1 °C in East Malaysia [47]. Based on the research projections, this country will face extreme drought and floods due to the climate changes [48]. At the Copenhagen Climate Change conference, Malaysian Prime Minister announced that the country was committed to reduce its carbon emissions by offering 'credible cut' of up to 40% by 2020.

Regarding the awareness of climate changes, the government is about to shift the energy policy in order to utilize the renewable energy sources instead of the conventional energy sources to decrease the emissions significantly [49–55]. Although, a lot of initiatives are taken, the amount of electricity generation from renewable energy sources is still not reached the target that set by government in Malaysia Ninth Plan. In Malaysia tenth plan, a new target was set to 985 MW generate electricity from renewable energy sources in 2015. The Government has launched several fiscal incentives to stimulate the emergence of renewable energy activities and technologies and is going to introduce the feed-in tariff mechanism in near future. The projection of energy consumption shows that it will increase to triple by 2030 from 2004, the utilization of renewable energy sources is a strategic option to improve the long term energy security and environment protection in Malaysia [56]. Biomass energy is the most potential energy source in Malaysia to overcome the increasing energy needs while preserving the environment [17,57–60]. Biomass residue is a promising fuel source for electricity generation that can reduce the CO_2 emission simultaneously [61]. As it is pointed in Ref. [62], wide spread of biomass cogeneration will result in greenhouse gas and also emission reduction.

3. Main biomass resources Malaysia

Biomass energy is an energy that is derived from living matter such as field's crops and trees. Agricultural and forestry wastes and municipal solid wastes are also considered in the biomass category [63]. Malaysia is endowed with abundant supplies of biomass resources. However, the main sources of biomass in Malaysia are come from plantation residue and agricultural residue.

3.1. Plantation residue

Plantation such as palm oil, rubber, cocoa, wood and timber and pepper is under supervised on the Ministry of Primary Industry and Commodities in Malaysia. These plantations are highly potential to be used as biomass residue for electricity generation. The statistical data shows that the production of biomass is increasing year by year especially palm oil, this is will be the advantages for electricity generation based on biomass residue in this country.

3.1.1. Palm oil

Malaysia is the second palm oil producer in the world after Indonesia. Development of palm oil in Malaysia is under supervision of the Malaysia Palm Oil Board. In 2009 Malaysia produced around 17,656,000 t of palm oil that was around 39% of the world production. Malaysia's total area of palm oil plantation is 4691,160 ha [64]. Being the second producer of palm oil the world, results in generating a significant amount of palm oil waste either in the plantation or in the mills. Only 60% of the palm fibers and shells, which are considered as the waste, are utilized as the boiler fuel in the mill to generate steam and electricity [65]. Most of the power plants use the steam turbine and it is observed that only a few power plants in palm oil mill industry use the waste of their products to generate electricity.

According to Ref. [66], Malaysia has 532 mills that work in palm oil sectors. The number and capacities of the palm oil sector are tabulated in Table 2 [66]. Among all these mills, only 10 mills have fully utilized the palm oil waste as the fuel resource. Given

Table 2
Number and capacities of palm oil sectors, January 2011 (Tons/Year).

Sector	Peninsular Malaysia		Sabah		Sarawak		Malaysia	
	No	Capacity	No	Capacity	Mills	Capacity	No	Capacity
FFB Mills	247	55,289,200	122	30,939,200	51	11,434,000	420	97,662,400
PK Crushers	26	3,952,800	14	2,329,200	4	583,200	44	6,865,200
Refineries	34	13,680,400	12	6,879,800	5	2,242,000	51	22,802,200
Oleo chemicals	17	2,598,971	–	–	–	–	17	2,598,971

Table 3
Palm oil production and it energy generation potential.

Year	Production (Mt)	EFB (Mt)	Fiber (Mt)	Shell (Mt)	E_{EFB} (PJ)	E_F (PJ)	E_S (PJ)	E_T (PJ)
0	48.05	20.57	7.06	2.35	127.59	51.97	37.13	216.69
1	50.98	21.82	7.49	2.49	135.37	55.14	39.39	229.9
2	50.88	21.78	7.48	2.49	135.12	55.04	39.31	229.47
3	55.37	23.69	8.14	2.71	147.03	59.89	42.78	249.71
4	57.39	24.56	8.44	2.81	152.38	62.07	44.34	258.79
5	60.66	25.96	8.92	2.97	161.07	65.61	46.87	273.54
6	63.83	27.32	9.38	3.13	169.48	69.04	49.32	287.84
7	78.6	33.64	1.16	3.85	208.71	85.01	60.73	354.45
8	87.75	37.56	1.28	4.29	233	94.91	67.79	395.71
9	90.07	38.55	1.32	4.41	239.17	97.42	69.59	406.18

Table 4
Sugarcane production and the potential energy generation.

Year	Sugarcane production (Mt)	Bagasse (Mt)	Top and Trashier (Mt)	$E_{Bagasse}$ (PJ)	$E_{Top\ and\ Trashier}$ (PJ)	E_{Total} (PJ)
2000	1.6000	0.4656	0.4832	3.352	2.521	5.873
2001	1.6000	0.4656	0.4832	3.352	2.521	5.873
2002	1.6000	0.4656	0.4832	3.352	2.521	5.873
2003	1.0000	0.2910	0.3020	2.095	1.576	3.671
2004	0.9500	0.2765	0.2869	1.990	1.497	3.487
2005	0.9500	0.2765	0.2869	1.990	1.497	3.487
2006	1.0000	0.2910	0.3020	2.095	1.576	3.671
2007	0.5599	0.1629	0.1691	1.173	0.882	2.056
2008	0.6939	0.2019	0.2095	1.454	1.093	2.547
2009	0.7000	0.2037	0.2114	1.467	1.103	2.570

the large amount of available palm oil waste, with the lack of landfill space, the ban of agriculture open burning and the large number of palm oil mills, there is a good potential for the biomass project using palm oil waste [65]. The study by Ref. [67] indicate that shell and fiber alone can generate more energy than the required energy for the palm oil mill. Table 3 shows the amount of palm oil productions and the potential energy that can be generated by palm oil waste [21,64]. The moisture content of the Empty fruit Bunch (EFB), fiber and shell are 60, 35 and 10%, respectively [67,68].

3.1.2. Sugarcane

The large areas in Northern region of Malaysia are dedicated to sugarcane plantation to supply the required sugar. From the biomass energy view, sugarcane cultivation produces granulated sugar, bagasse and dry leaves and cane tops that can potentially be converted into useful energy. The sugarcane industry produces sugarcane bagasse that can be used in the cogeneration process to generate electricity. Sugarcane bagasse is the fibrous waste that remains after recovery of sugar juice via crushing and extraction. A ton of bagasse (50% mill-wet basis) is equal to 1.6 barrels of fuel oil on the energy basis. The total of sugarcane energy content on the dry basis, excluding ash is around 2 to 3% of weight). Malaysia produces 700,000 t of sugarcane in 2009, with a moisture content of 50%. The caloric value for dry bagasse estimated to be 14.4 MJ/kg [69], so this amount of sugarcane resulted in 0.421 million BOE per year potential energy. This is huge number for usage in energy application such as in electricity generation. At the moment, all the bagasse is being used as boiler fuels for sugar mills operation in the country.

Leaves and cane tops which form around 68.5% of the sugarcane wasted are burnt up during the replanting process. The average caloric value for both wastes is reported to be 17.39 MJ/kg [70]. Therefore, 0.298 Million BOE of energy per year can be produced from them. Table 4 indicates the amount of sugarcane productions from 2000 to 2009 [71]. The potential of energy generation from sugarcane residue is also calculated.

Table 5
Malaysia total forested area and area under tree crops as compared to total land area.

Year	Total land area	Forested area	%	Other tree crops area	%	Non forested area	%
2000	33	20.20	61.2	4.8	14.6	8.0	24.2
2001	33	20.20	61.2	4.8	14.6	8.0	24.2
2002	33	19.92	60.4	4.8	14.6	8.3	25.1
2003	33	19.92	60.4	4.8	14.6	8.3	25.2
2004	33	19.49	59.1	4.8	14.5	8.7	25.4
2005	33	19.49	59.1	4.8	14.5	8.7	26.4
2006	33	19.49	59.1	4.8	14.5	8.7	26.4
2007	33	19.47	59.0	4.8	14.5	8.7	26.4
2008	33	18.08	55.0	0.8	2.5	14.0	42.7
2009	33	18.08	54.8	0.9	2.7	14.0	42.4

3.2. Other agriculture residue

Malaysian agriculture sector contribution to Gross Domestic Product (GDP) in 2010 was around 10.6%. It means that, this sector provides a significant amount to the development of economic in this country. Agriculture crop residues are divided into two categories of crop residues and agricultural industry product [72]. This crop's residues are the potential sources of bio-energy that can be used as heat or electrical energy. Since biomass resources are dependent on land availability, it becomes one of the main constraint of biomass development [73]. The agriculture sector utilizes 20% of the total land in the country. Table 5 indicates the Malaysia total forested and crop compared to total land [74].

In Malaysia, agricultural products like, coconut, cocoa, pepper, pineapple, tobacco, coffee, tea and sugarcane are the most important products. These crops are utilized for nutrition supply and are controlled by Ministry of Agriculture and Agro-Based Industry. Fig. 1 shows the total area under selected crops from 2000 to 2009 [74].

Rice's husk is the major potential source for biomass based power generation in Malaysia after wood and palm oil [75]. The north part of Malaysia is the rice bowl of the country. The

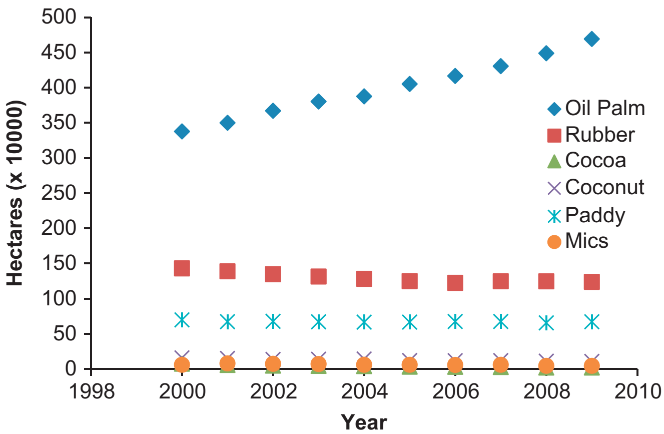

Fig. 1. Total area under selected crops (hectares).

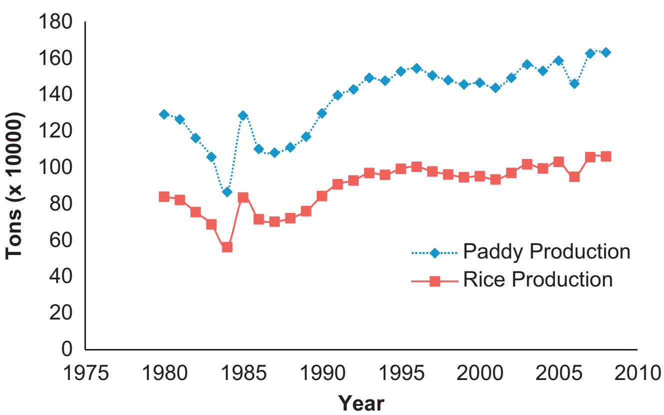

Fig. 2. Paddy and rice production.

statistical data shows that in 2008 paddy production in this area was around 1632,507 t [76]. There are two seasons of paddy planted in Malaysia, the main season refers to the period of paddy planting 1st of August to 28th February and off season covers the period of paddy planting from 31st March to 31st July of the year. Paddy straws and rice husks are the main residues from paddy cultivation that are generated during the harvesting and milling processes. The paddy straw is left in the paddy field and rice husk is generated in the rice mill. Both of the mare discharged by landfill and open burning. The amount of rice husk and paddy straw generated in future is dependent on the planted area, the paddy yield and government policy. There is a significant potential to improve the productivity of the paddy sector from the current yield level of 3–5 t per hectare to around 8 t per hectare by 2012, and 9–10 t per hectare by 2020 [77]. With this valuable target, more rice husk and paddy straw will be available for biomass CHP plant. Around 20% of paddy is husk, rice husk in turn contains 16 to 22% ash and 90 to 96% of the ash is composed of silica (silicon dioxide, SiO_2). Out of 1632,507 t of rice produced in 2008, 23% is rice husk with moisture content between 13% and 14%. This means that 326,664.65 t of dry husks were produced. According to Ref. [77], by the year 2020 Malaysia will produce around 768,290 t of rice husks.

In the Northern region of Malaysia only two rice mill use their residues to generate electricity. It means among the large amount of the produced rice husk only a small amount of them is used for energy production. Both of these mills consume up to 240 t of rice husk per day, or approximately 86,400 per annum for generating the power of 700 kW to 1500 kW. Paddy and rice production in North region of Malaysia is presented in Fig. 2 [78].

Rice's husk cogeneration in Malaysia is under EC-ASEAN COGEN program that is a cogeneration program initiated by European Commission (EC) and Associated of South East Asian Nation (ASEAN). Three phases of COGEN programs were successfully implemented in the period of 1991–2004. Ban Heng Bee Rice Mill that using rice husk as a fuel was the program under COGEN phase 1. At this mill, rice husks from the rice mill were used in the water-cooled step gate furnace to produce 30 t per hour of 22 bar steam. The plant generates 470 kW of electricity used in for the milling processes. Based on the study conducted by Ref. [79], the raw rice husk ash has good mechanical properties that made this material suitable for construction materials. Applying the cogeneration program to the rice mill not only overcomes the problem of the management of rice husk, but also gives the benefit from selling the ash and electricity generated.

4. Other potential biomass resources

Pineapple's waste is another potential waste, as it is one of the main commodities in Malaysia for either domestic or export market. Nowadays, pineapple waste is not fully utilized and usually burnt. In 2009, the production of pineapple was reported to be around 114,958 t. About 74.37% of pineapple productions were under estate management while the rest were under small holder cultivation. Pineapples are mostly consumed for the nutrition purposes either as a fresh product or processed fruit. Only 20% of the pineapple is canned for nutrition usage and the rest, which includes peeled skin, core, base and crown are discharged as waste [80]. The waste and the pineapple's bran account for 50% of the total pineapple's weight [81]. Fig. 3 illustrates the production of pineapple in Malaysia and the potential energy that can be generated by pineapple's residue [13]. The potential energy is estimated using the "residue-to-product" ratio [82]. About 45% of the fresh fruit become the solid residual [83]. A lower heating value for pineapple is set to be 0.0116 TJ/t [11]. In 2008, the productions of solid residual of pineapples were 70,249 t. This residual is potential to generate roughly 1.8×1015 MW h of electricity. Philippine currently study to generate 4 MW power using 220 t/day of pineapple's pulp [84].

Coconut is the third important industrial crop in terms of the total planted area in Malaysia. The world leading producer of coconut is Philippine [71]. Coconut development in Malaysia is under the agriculture and agro industries program. In 2009, the local coconut oil production was reported to be around 455,000 t. Currently, Malaysia Agriculture Research Development Institute (MARDI) was carryout research on the usage of coconut for the commercialization purpose. Table 6 presents the total energy potential generated by coconut residue [71].

Malaysia wood processing industries can be also determined as one of the biomass resources for power generation. These industries are one of the largest untapped biomass and co-generation potential in the country. Malaysia has only five mills in the countries that use wood waste as fuel and produce between 900 kW and 10 MW of energy. Therefore, the wood industry has the potential of increasing the number of the unit that can work with wood waste based fuels. Table 7 indicates the different types of wood that are produced in Malaysia [85].

5. Technology

The availability of technologies available for electricity generation from biomass are direct combustion, gasification and

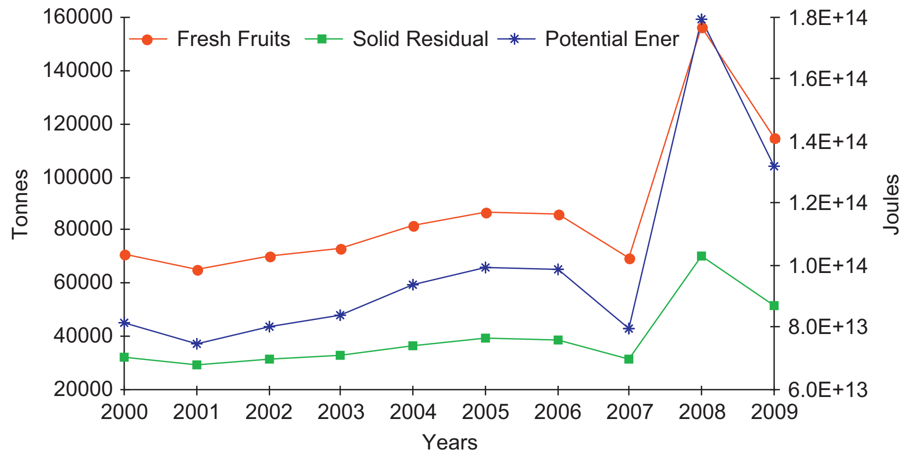

Fig. 3. Production of pineapples and potential energy.

Table 6
Coconut production and the potential energy generated from it during 2000–2009.

Year	Coconut (Mt)	Husk (Mt)	Energy (PJ)	Shell (Mt)	Energy (PJ)	Empty bunches (Mt)	Energy (PJ)	Frond (Mt)	Energy (PJ)	Total energy (PJ)
2000	0.734	0.266	4.315	0.118	2.107	0.036	0.554	0.165	2.644	9.620
2001	0.712	0.258	4.183	0.114	2.043	0.035	0.537	0.160	2.563	9.326
2002	0.712	0.258	4.183	0.114	2.043	0.035	0.537	0.160	2.563	9.326
2003	0.580	0.209	3.408	0.928	1.664	0.028	0.438	0.131	2.088	7.597
2004	0.624	0.226	3.666	0.998	1.790	0.031	0.471	0.140	2.246	8.174
2005	0.571	0.207	3.355	0.914	1.638	0.028	0.431	0.128	2.056	7.479
2006	0.513	0.186	3.012	0.820	1.471	0.025	0.387	0.115	1.846	6.716
2007	0.503	0.182	2.957	0.805	1.444	0.024	0.380	0.113	1.812	6.592
2008	0.455	0.165	2.676	0.729	1.306	0.022	0.344	0.102	1.639	5.965
2009	0.459	0.166	2.701	0.735	1.319	0.022	0.347	0.103	1.655	6.021

Table 7
Wood raw material production in Malaysia ('000 m^3).

Year	Logs	Sawn timber	Plywood	Veneer	Moulding
2000	23,075	5556	4434	1116	715
2001	18,922	4823	4389	651	273
2002	20,469	4602	4301	763	381
2003	21,528	4819	4710	643	441
2004	22,039	4854	4977	486	532
2005	22,363	5084	3481	435	618
2006	21,983	5138	5440	612	404
2007	22,051	5064	5439	732	455
2008	20,260	4466	4837	1004	341
2009	18,336	3849	3655	753	–
2010[a]	12,236	2866	3437	869	–

[a] January–June 2010.

pyrolysis [86,87]. Table 8 [88] lists the biomass power technology in commercial/demonstration during 2000–2006. The maximum capacities of electricity generation from biomass resource are 300 MW. Majority of biomass fuel are from wood waste categories. A lot more research on agriculture residue should be explore to variety the biomass fuel consumption.

5.1. Combustion

The most widely use and establish application are direct combustion of solid biomass [89] while gasification and pyrolisis are still in development stages [90]. It contributes to over 97% of bio-energy production in the world [91]. Combustion, used to convert biomass energy into heat then electricity energy base on thermo-chemical process with output production of hot gases at temperature around 800–1000 °C [92]. Theoretically, combustion can be suited for any type of biomass resources but commonly practices the combustion is feasible only for biomass with moisturize content less $<50\%$ [92].

The main combustion system can be distinguished to fixed bed combustion, fluidised bed combustion and dust combustion.

5.2. Gasification

Gasification is a thermal breakdown of the biomass particle into gas with existing of oxidation agent (air, oxygen, water, carbon dioxide, etc). By converting biomass into a gas, it can make available into broad range of energy devices. Gasification is the intermediate step between pyrolysis and combustion. The gas can be used in more efficient power generation system called combined cycles which are combine steam turbine and gas turbine. Gasification has been practiced for many years and Table 9 [93] lists of thermal gasification commercial facilities.

5.3. Pyrolysis

Pyrolysis of biomass is the thermal degradation of the material (without oxidation), and occurs prior to or simultaneously with gasification reactions in a gasifier. And biomass is converted to liquids, gas and char. The biomass pyrolysis is attractive because solid biomass and wastes can be readily converted into liquid products [94]. Pyrolysis produces energy fuels with high to feed ratios, making it the most efficient process for biomass conversion and the method most capable of competing with non-renewable fossil fuel resources [95]. The pyrolysis can be divided into three subclasses: slow pyrolysis, fast pyrolysis and flash pyrolysis. The ranges of important parameters for pyrolysis processes are given in Table 10.

Table 8

Technology category	Biomass conversion technology	Primary energy form produced	Commonly use fuel types	Particle size requirements (mm)	Moisture content requirement (% wet basis)	Average capacity range (MWe)
Direct conversion	Stove/furnace	Heat	Solid wood, pressed logs, wood chips and pellets	Limited by stove size and opening	10–30	
	Pile burners	Heat, steam	Wood residue and agriculture residue	Limited by grate size and feed opening	< 65	4 to 110
	Stoker grate boiler	Heat, steam	Sawdust, non-stringy bark, shavings, end cuts, chips, chip rejects, hog fuel	6–50	10–50	20–300
	Suspension boiler	Heat, steam	Sawdust, non-stringy bark, shavings, flour, sander dust, wood flour, sander dust, processed sawdust	1–6	< 20	1.5–30
	Fluidized bed combustor	Heat, steam	Low alkaline content fuels, mostly wood residues or peat or stringy material	< 50	< 60	300
Gasification	Current fixed bed	Low Btu gas	Chipped wood, rice hulls, dried sewage sludge	6–100	< 20	5–90
	Downdraft, moving bed		Wood chips, pellets, wood scrapes, nut shells	< 50	15	25–100
	Circulating fluidized bed	Medium Btu gas	Most wood and chipped agricultural residues	6–50	15–50	5–10
Pyrolysis	Reactors	Pyrolysis oil, charcoal	Variety wood and agricultural resource	1–6	< 10	2.5

Table 9
Thermal gasification commercial facilities.

Name	Country	Raw material	Thermal output (MW)	Electricity output (MW)	Technology
Andritz-Carbona	Denmark	Lignocelluloses, wood pellets	11	5.5	Fluidized bed reactor
Bubcock and Wilcox Volund	Denmark	Lignocelluloses, wood chips	3.5	1	Reactor updraft gasifier
Bubcock and Wilcox Volund	Japan	Lignocelluloses, wood chips	12	-	Updraft gasifier
Bubcock and Wilcox Volund	Japan	Lignocelluloses, wood chips	8	2	Updraft gasifier
Biomass Engineering Ltd	UK	Lignocelluloses, wood chips	-	1	Downdraft gasifier
Biomass Engineering Ltd	UK	Lignocelluloses, wood chips	-	0.25	Downdraft gasifier
FICFB	Austria	Lignocelluloses, wood chips	4.5	2	FICFB gasification
FICFB Oberwart	Austria	Lignocelluloses, wood chips	1–6	2.7	FICFB gasification
CHP Urban Neumarkt	Austria	Clean wood, biomass	0.58	0.240	Downdraft gasifier
CHP Urban Sulzbach-Laufen	Germany	Waste wood, biomass	0.28	0.13	Downdraft gasifier
CHP Heatpipie Reformer	Germany	Lignocelluloses, waste wood, clean wood	0.25	0.11	FB
CHP Urban Neunkirchen	Austria	Lignocelluloses, waste wood, clean wood	0.62	0.3	Downdraft gasifier
CHP Pyroforce Nidwalden	Switzerland	Lignocelluloses, dried chips	1.2	2×0.69	Downdraft pyroforce gasifier
CHP Wila	Switzerland	Lignocelluloses, dried chips	0.45	0.35	Downdraft woodpower gasifier

Table 10
Main operating parameter for pyrolysis processes.

Pyrolysis	Heating rate (K/s)	Residence time (s)	Temperature (°C)	Particle size (mm)	Product
Slow	< 1	300–1800	400	5–50	Char
			600		Gas, oil, char
Fast	$500–10^5$	0.5–5	500–650		70% oil
				< 1	15% char
					15% gas
Flash	$> 10^5$	< 1	< 650	< 0.2	Oil
		< 1	> 650		Gas
		< 0.5	1000		Gas

6. Economic analysis and energy efficiency of electricity generation from biomass resources

Electricity generation cost depends on investment cost and variable cost, which are including the capital cost, operational, maintenance and fuel cost. Additional factors effect to the cost of biomass based power generation are power capacity, power plant life time, heat and electricity efficiency and load factor of power plant [96]. Literature cost for biomass power production is shown in Table 11 [89,97–106]. To overcome the limitation of biomass based power generation cost, developers must take a long term view and continue to exploit emerging technologies that can reduce the electricity generation cost from biomass resources.

Energy efficiency are varies depending on technology used for conversion process. This area always gives much attraction to achieve much efficient energy conversion. Energy efficiency on different energy conversion process of biomass resources is shown in Table 12 [107–109]. The average efficiency of all technologies is 0.2995.

7. Challenges for biomass based power generation

Although the use of biomass resources in power generation has a lot of benefits, it also faces numerous challenges. Table 13

Table 11
Electricity cost from biomass based electricity generation.

Year	Author	Fuel	Country	Technology	Capacity (MW)	Electricity cost ($/kW h)
2002	Bridgwater et al.	Wood chip	Europe	Pyrolysis	20	0.1136
2002	Wu et al.	Rice husk	China	Gasification	1	0.0425
2003	Kumar et al.	Agriculture residue	Canada	Combustion	450	0.0503
2003	Kumar et al.	Whole forest biomass	Canada	Combustion	900	0.0472
2003	Kumar et al.	Forest residue	Canada	Combustion	137	0.0630
2007	Nouni et al.	Wood	India	Gasification	$(5\ 4\ 0) \times 10^{-3}$	0.30–0.55
2009	Dwivedi and Alavalapati	Bio-energy crop	India	Gasification	0.1	0.1500
2010	Kumar	Corn	USA	Gasification	–	0.1351
2011	Delivand et al.	Rice straw	Thailand	Direct combustion	5–20	0.0676–0.0899
2011	Rendeiro et al.	Forest residue	Brazil	Thermoelectric	0.05	0.7640
2011	Yagi and Nakata	Thinned wood	Japan	Gasification	0.3	0.2000
2012	Dassanayake and Kumar	Triticale straw	Canada	Direct combustion	300	0.0763 ± 0.00476
2012	Upadhyay et al.	Forest harvest residue	Canada	Gasification	50	0.0604–0.0623

Table 12
Energy efficiency on biomass energy conversion processes.

Power generation method	Ref.	Fuel type	Efficiency
Direct combustion			0.19–0.26
Thermal gasification combined cycle			0.16–0.30
Supercritical water gasification combined cycle	[107]	Biomass	0.29
Methanol-fired			0.26
Anaerobic digestion of biomass			0.40
Gasified cogeneration system	[108]	Vegetable and animal	0.22
Fluidized bed gasification combined cycle			0.42
Fluidized bed gasification gas engine	[109]	Wood waste	0.34
Fluidized bed combustion steam turbine			0.31
Grate firing			0.3

Table 13
Summarize the main constrains for biomass based power generation at Malaysia.

Author/s	Year	Focus	Limitation		
			Technical	Financial	Policy
Koh and Hoi [58]	2003		No local expertise for efficient biomass energy conversion	High energy production	Lacking of awareness regarding the renewable energy consumption
Jaafar et al. [110]	2003	Green energy	Reliable of supply	Lack of financial supports Very expensive due to lacking of economies of scale in RE projects	Poor perception about the potential and commercial viability of RE
Mohammed and Lee [111]	2006		Development of conversion technology is not establish No commercialization on large scale in RE generation	RE generation cost is competitive with cheaper fossil fuel cost	Lacking of reliable information on the potential supply of RE at the national level
Ahmad et al. [50]	2011		Lack of technical knowledge has lead o poor quality product	Malaysia provide enormous subsidy that results in a cheap electric price from national grid	Lack of interest from commercial investors
Sovakool and Drupady [54]	2011	SREP	Lack of new technology Insufficient education, training and sharing experience among all stakeholders	Low electricity tariffs for renewable power producers Unfamiliarity and resistance from financial and bakers	Lack of strongly implemented national policy frameworks Flaws in program design
Ali et al. [112]	2012	Malaysia renewable energy	Lacking of local expertise in efficient handling equipment	Market price of RE system will be high to compensate the cost of R and D Difficulty to get financial loan	Unattractive to potential inventor due to available of cheaper conventional energy sources
Saidur et al. [59]	2011	Biomass	No local manufactures for the efficient conversion of biomass to energy	High energy production cost No subsidy for energy production from RE sources Lacking of financial/credit mechanism	No national strategy given to encourage biomass for energy use Lacking of information/awareness, among different national agencies

[58,110,111,50,54,112,59] summarize the main constrains for biomass based power generation at Malaysia.

The main limitations for biomass based power generation can categorize into technical constraint, economic constraint and policy constraint. The issues are discuss refer to Malaysia country.

8. Current situation Malaysia biomass based power generation

As tropical country Malaysia have plenty of biomass resources. Table 14 lists the biomass based power generation at Malaysia.

Table 14
Lists the biomass based power generation at Malaysia.

No:	Company name	Biomass fuel	Capacity (MW)	Electricity generate (MW h)
1.	TSH bio energy Sdn. Bhd.	Waste from palm oil	14	79,246
2.	Seguntor bioenergy	EFB	11.5	67,543
3.	Kina biopower Sdn. Bhd.	EFB	11.5	67,570
4.	Recycle energy Sdn. Bhd.	Refused derive fuel	8.9	7,032
5.	Bell eco power Sdn. Bhd.	Palm oil mill effluent	2	1,436
6.	Achi Jaya Plnatations Sdn. Bhd.	Palm oil mill effluent	1.25	–
7.	Bahagaya Sdn.Bhd.	EFB	3	20,130
8.	Bio-fuel Sdn.Bhd.	Wood waste	10	306
9.	Evergreen intermerge Sdn.Bhd.	EFB	6	10,289
10.	Seo energy Sdn.Bhd.	EFB	1.2	2,565
11.	IJM biofuel Sdn. Bhd.	EFB	3.6	–
12.	IOI bio-Energy Sdn.Bhd.	Empty fruit bunch	15	
13.	Bernas production Setia Sdn.Bhd.	Rice husk	0.2	
14.	Padi Beras national Bhd.	Rice husk	0.7	106
15.	Sime Darby plantations Sdn.Bhd, Selangor	Agriculture residue	3.4	3,845
16.	Sime Darby plantations Sdn.Bhd, Perak	Agriculture residue	1.5	4,070
17.	Malaysian Newsprint Industries Sdn. Bhd.	Agriculture residue	79.2	27,628
18.	Tian Siang oil mill (Perak) Sdn.Bhd.	Agriculture residue	4.8	371
19.	Nibong Tebal paper mill Sdn.Bhd.	Wood dust	0.8	
20.	Ban Heng Bee rice mill	Rice Husk	0.5	2,837
21.	Felda palm industries Sdn.Bhd.	EFB	7.5	19,640
22.	Palm energy Sdn.Bhd.	Agriculture residue	6.5	11,103
23.	Sabah forest industries Sdn. Bhd.	Wood waste	57	282,613
24.	Gula Padang Terap Sdn.Bhd	Agriculture residue	10.3	24,804

Table 15
Biomass component collected in 2009 and their potential electricity generated.

Biomass component	Caloric value (MJ/kg)	Electricity generated (GW h)
Palm oil residue [113]		
Shell	23.51	5792.13
Fiber	22.07	1578.19
EFB	21.52	46346.15
Coconut residue		
Shell	20.15 [114]	0.84
Bunches	19.6 [115]	0.02
Frond	19.6 [115]	0.11
Husk	19.6 [115]	0.18
Paddy residue		
Rice husk	15.8 [117]	0.51
Rice straw	14.71 [118]	1.59
Sugarcane		
Bagasse	18.11 [116]	0.21
Top and Trashier	17.45 [116]	0.21

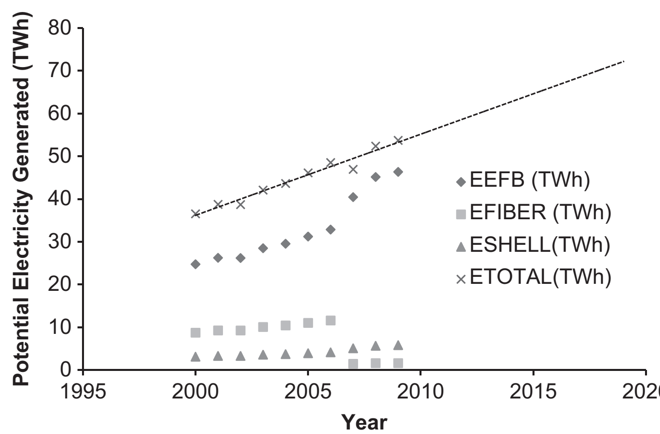

Fig. 4. Potential electricity generated from palm oil residue.

As review in the previous chapter, biomass resources are widely available in the country. Despite it wide use already, there still much more possibility to optimize the utilization of biomass resource at Malaysia.

The amount of each type of biomass component in 2009 and their potential electricity generated is shown in Table 15. All the biomass resources are converted into electricity power, considering the caloric value of each component shown in Table 15 [113–118]. The corresponding electricity generated and amount of biomass fired are function of net plant heat rate [119].

Recently, Malaysia shows an increasing pattern of oil palm production. In 2011, the productions of fresh fruit bunch are 98.45 Mt which are 100% increased in 10 years. Parallel to this, the oil palm residue production also shown same pattern. Fig. 4 show the potential of electricity generated from oil palm residue. The analysis use 17.9 MJ/kW h as default net plant heat rate (NPHR) of oil palm residue fired alone [120]. It forecast in 2020 about 70 TW h can potentially be generating by using the oil palm residue.

The potentially of electricity generated from agriculture residue is shown in Table 16. It seem the palm oil residue contribute the highest percentage in electricity generation compare with others.

Table 16
Potentially of agriculture residue based electricity generation.

Year	$E_{\text{Total coconut residue}}$(kW h)	$E_{\text{Total sugarcane residue}}$ (kW h)	$E_{\text{Total paddy residue}}$ (kW h)	E_{Total} (kW h)
2000	646,491.62	941,574.9721	1785,133	3373,199
2001	626,581.006	941,574.9721	1746,853	3315,009
2002	626,581.006	941,574.9721	1832,199	3400,355
2003	1,465,743.02	588,484.3575	1881,967	3936,194
2004	1,577,664.8	559,110.7263	1910,580	4047,356
2005	14,44,234.64	559,110.7263	1929,779	3933,124
2006	1,296,067.04	588,484.3575	1824,001	3708,553
2007	1,271,223.46	329,471.0615	1980,830	3581,525
2008	1,151,335.2	408,267.8212	1962,009	3521,612
2009	1,160,396.65	411,939.0503	2093,762	3666,098

9. Others application of biomass resources at Malaysia

In addition to power generation, biomass can be converted to bio-fuel such as bio-ethanol, bio-diesel and bio-methanol. The processes to produce bio-diesel are pyrolysis, microemulsion, dilution and transesterification [121]. These methods are used

to overcome the problem of compression-ignition engines due to high viscosity of oil [122]. Transesterification is the best method chooses with high conversion efficiency, low cost and suitable for industry application [123]. As the world largest palm oil producer, Malaysia can be the main palm oil producer. In 2006, Malaysia introduce ENVO diesel, a mixture of 5% blend of processed palm oil with 95% petroleum derived diesel. However this project is failed and government of Malaysia implemented the mandatory use of bio-fuel for vehicle in 2011 [124]. Bio-fuel was produced from biomass through a process know fast pyrolysis. Up to date, this process has received a small attention from Malaysian researcher [125].

Currently, researcher is focusing towards the hydrogen production from biomass resources since it is expected to become a major source of energy. Paper [126], reviews some potential biomass-based hydrogen production methods based on two main conversions which are thermo-chemical and bio-chemical. But biomass gasification method offers the earliest and most economical route for the hydrogen production [127]. Hydrogen production from biomass resource has major challenge since there are no completed technology demonstrations yet [128]. The cost analysis, for EFB as a feedstock using gasification process in bench scale fluidized bed gasified showed that the hydrogen supply cost is RM 6.7/kg EFB ($0.18/Nm^3$) [129].

10. Conclusions

Due to the government target to enhance the consumption of renewable energy, agricultural and industrial residue in this country can be considered as one of the renewable energy sources. Biomass residues create high potential for electricity generation in Malaysia. The most potential is using empty fruit bunch, fiber and shell of palm oil. Since Malaysia has abundant amounts of agricultural and industrial residues, it has potential energy that can be utilized in different sectors. Using biomass residues has economic, environmental and also political benefits. However, lack of expert in optimization biomass residue makes the country still low in utilization of biomass therefore most of industries are not aware this benefit and they are reluctant to take the risk on utilization of biomass for power generation.

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References

[1] Chiari L and Zecca A, Constraints of fossil fuels depletion on global warming projections. Energy Policy. 39(9): 5026–34.
[2] Hoel M, Kverndokk S. Depletion of fossil fuels and the impacts of global warming. Resource and Energy Economics 1996;18(2):115–36.
[3] Nel WP, Cooper CJ. Implications of fossil fuel constraints on economic growth and global warming. Energy Policy 2009;37(1):166–80.
[4] Sebitosi AB. Energy efficiency, security of supply and the environment in South Africa: moving beyond the strategy documents. Energy 2008; 33(11):1591–6.
[5] Jayed MH, et al, Prospects of dedicated biodiesel engine vehicles in Malaysia and Indonesia. Renewable and Sustainable Energy Reviews. 15(1): 220–235.
[6] Mahlia TMI, et al. An alternative energy source from palm wastes industry for Malaysia and Indonesia. Energy Conversion and Management 2001;42(18):2109–18.
[7] Mazandarani A, et al, Investigating the need of nuclear power plants for sustainable energy in Iran. Renewable and Sustainable Energy Reviews. 15(8): 3575–3587.
[8] Ong HC, Mahlia TMI, and Masjuki HH, A review on energy pattern and policy for transportation sector in Malaysia. Renewable and Sustainable Energy Reviews, (0).
[9] Ong HC, et al, Comparison of palm oil, Jatropha curcas and Calophyllum inophyllum for biodiesel: a review. Renewable and Sustainable Energy Reviews. 15(8): 3501–15.
[10] Silitonga AS, et al, A review on prospect of Jatropha curcas for biodiesel in Indonesia. Renewable and Sustainable Energy Reviews. 15(8): 3733–56.
[11] Singer S, The energy report 100% renewable energy by 2050, in WWF The energy report 2011, WWF International: Switzerland. p. 1–256.
[12] Ho MW, Cherry B, Burcher S, and Saunders P, Green energies 100% renewables by 2050. Germany 100% renewables by 2050 2009: Oxford: ISIS. 181.
[13] Conti J, and Holtberg P, International Energy Outlook 2011, U.S.E.I. administration, editor 2011, Independent statistics and analysis: United State.
[14] Renewable energy generation, 2008, International Energy Agency: United State.
[15] PTM Annual Report 2009, P.T. Malaysia, Editor 2009: Kuala Lumpur, Malaysia.
[16] Mahlia TMI and PL Chan, Life cycle cost analysis of fuel cell based cogeneration system for residential application in Malaysia. Renewable and Sustainable Energy Reviews. 15(1): 416–26.
[17] Hoi Why K, Biomass energy utilisation in Malaysia â€" prospects and problems. Renewable Energy. 16(1–4): 1122–7.
[18] Shafie SM, et al, Current energy usage and sustainable energy in Malaysia: a review. Renewable and Sustainable Energy Reviews, (0).
[19] Shekarchian M, et al, A review on the pattern of electricity generation and emission in Malaysia from 1976 to 2008. Renewable and Sustainable Energy Reviews. 15(6): 2629–42.
[20] TMI M. Emissions from electricity generation in Malaysia. Renewable Energy 2002;27(2):293–300.
[21] Ong HC, Mahlia TMI, Masjuki HH. A review on energy scenario and sustainable energy in Malaysia. Renewable and Sustainable Energy Reviews 2011;15(1):639–47.
[22] Bhattacharya SC. Biomass energy in Asia: a review of status, technologies and policies in Asia. Energy for Sustainable Development 2002:5–106 2002:5–10.
[23] BW A. Electricity-output ratio and sectoral electricity use the case of East and Southeast Asian developing countries. Energy Policy 1988;16(2):115–21.
[24] Hiroaki N. Effects of regulatory reforms in the electricity supply industry on electricity prices in developing countries. Energy Policy 2007;35(6):3440–62.
[25] Kanagawa M, Nakata T. Assessment of access to electricity and the socio-economic impacts in rural areas of developing countries. Energy Policy 2008;36(6):2016–29.
[26] Maruyama N, Eckelman MJ. Long-term trends of electric efficiencies in electricity generation in developing countries. Energy Policy 2009;37(5):1678–86.
[27] Meyers S, Sathaye J. Electricity use in the developing countries: changes since 1970. Energy 1989;14(8):435–41.
[28] Nagayama H, Kashiwagi T. Evaluating electricity sector reforms in Argentina: lessons for developing countries? Journal of Cleaner Production 2007;15(2):115–30.
[29] Pollitt M, Stern J. Human resource constraints for electricity regulation in developing countries: developments since. Utilities Policy 2001;19(2):53–60.
[30] Williams JH and R Ghanadan, Electricity reform in developing and transition countries: a reappraisal. Energy. 31(6–7): 815–44.
[31] dan Statistik Maklumat Prestasi, Elektrik Indusrti Pembekalan. In: Tenaga S, editor. di Malaysia. Kuala Lumpur, Malaysia: Suruhanjaya Tenaga; 2009.
[32] Ang JB. Economic development, pollutant emissions and energy consumption in Malaysia. Journal of Policy Modeling 2008;30:271–8.
[33] Boudri JC, et al. The potential contribution of renewable energy in air pollution abatement in China and India. Energy Policy 2002;30(5):409–24.
[34] Lee S, Jo J. Evaluating policy measures' effectiveness in reducing energy consumption and air pollution: case study of Seoul. Science of The Total Environment 1995;169(1-3):289–93.
[35] Midttun A, Chander I. The political economy of energy use and pollution: the environmental effects of East-European transition to market economy. Energy Policy 1998;26(13):1017–29.
[36] Ocak M, et al. Energy utilization, environmental pollution and renewable energy sources in Turkey. Energy Conversion and Management 2004;45(6):845–64.
[37] MS. Fossil fuel and greenhouse gas mitigation technologies. International Journal of Hydrogen Energy 1994;19(8):659–65.
[38] Reijnders L, Huijbregts MAJ. Life cycle greenhouse gas emissions, fossil fuel demand and solar energy conversion efficiency in European bioethanol production for automotive purposes. Journal of Cleaner Production 2007;15(18):1806–12.
[39] Schmidt J, Gass V, and Schmid E, Land use changes, greenhouse gas emissions and fossil fuel substitution of biofuels compared to bioelectricity production for electric cars in Austria. Biomass and Bioenergy. 35(9): 4060–74.
[40] Schmidt J, et al, Cost-effective policy instruments for greenhouse gas emission reduction and fossil fuel substitution through bioenergy production in Austria. Energy Policy. 39(6): 3261–80.
[41] Smith KR, et al, Greenhouse gases from biomass and fossil fuel stoves in developing countries: a Manila pilot study. Chemosphere. 26(1–4): 479–505.
[42] VeziroÇşlu TN, GÃrkan I, Padki MM. Remediation of greenhouse problem through replacement of fossil fuels by hydrogen. International Journal of Hydrogen Energy 1989;14(4):257–66.

[43] von Hippel D, et al. Estimating greenhouse gas emissions from fossil fuel consumption two approaches compared. Energy Policy 1993;21(6):691–702.
[44] WS. Avoiding excessive greenhouse effect by delayed emission of carbon dioxide from the fossil-fuel cycle. Applied Energy 1995;51(1):39–49.
[45] Qader MR. Electricity consumption and GHG emissions in GCC countries. Energies 2009;2:1201–13.
[46] Mahlia TMI. Emission from electricity generation in Malaysia. Renewable Energy 2002:293–300.
[47] Press, Winds of change look bad, in The Star Online 2011: Malaysia.
[48] Press, Early warning system needed for floods, in The Star Online 2011: Malaysia.
[49] Abdul RM, Lee KT. Energy for sustainable development in Malaysia: energy policy and alternative energy. Energy Policy 2005;34:2388–97.
[50] Ahamd S, MZAA Kadir, and S Shafie, Current perspective of the renewable energy development in Malaysia. Renewable and Sustainable Energy Reviews. 15(2): 897–904.
[51] Gan PY, Li Z. An econometric study on long-term energy outlook and the implications of renewable energy utilization in Malaysia. Energy Policy 2008;36(2):890–9.
[52] Haidar AMA, PN John, and M Shawal, Optimal configuration assessment of renewable energy in Malaysia. Renewable Energy. 36(2): 881–8.
[53] Poh KM, Kong HW. Renewable energy in Malaysia: a policy analysis. Energy for Sustainable Development 2002;6(3):31–9.
[54] Sovacool BK, Drupady IM. Examining the Small Renewable Energy Power (SREP) Program in Malaysia. Energy Policy 2011;39:7244–56.
[55] Sumathi S, Chai SP, Mohamed AR. Utilization of oil palm as a source of renewable energy in Malaysia. Renewable and Sustainable Energy Reviews 2008;12(9):2404–21.
[56] Gan PY, Li Z. An econometric study on long term energy outlook and implications of renewable energy utilization in Malaysia. Energy Policy 2008;36:890–9.
[57] Abnisa F, et al, Utilization possibilities of palm shell as a source of biomass energy in Malaysia by producing bio-oil in pyrolysis process. Biomass and Bioenergy. 35(5): 1863–72.
[58] Koh MP, Hoi WK. Sustainable biomass production for energy in Malaysia. Biomass and Bioenergy 2003;25(5):517–29.
[59] Mekhilef S, et al. Biomass energy in Malaysia: current state and prospects. Renewable and Sustainable Energy Reviews 2011;15(7):3360–70.
[60] Mohammed MAA, et al., Hydrogen rich gas from oil palm biomass as a potential source of renewable energy in Malaysia. Renewable and Sustainable Energy Reviews. 15(2): 1258–70.
[61] Muis ZA, Hashim H, Manan ZA, Taha FM. Optimization of biomass usage for electricity generation with carbon dioxide reduction in Malaysia. Journal of Applied Sciences 2010;10:2613–7.
[62] Duval Y. Environmental impact of modern biomass cogeneration in Southeast Asia. Biomass and Bioenergy 2001;20:287–95.
[63] Hinrichs RA, and Kleinbach M, Energy its use and the environment. 4th ed. ed2006: Thomson Brooks/Cole.
[64] Malaysia Oil Palm Statistics 2009, 2009, Economics and Industry Development Division MPOB: Malaysia.
[65] Mokanatas ER, Use palm oil waste for biomass project., in The Star Online 2010.
[66] Economics and Industry Development Division Website. 2011 [cited 2011 Mach,1]; Available from: 〈http://econ.mpob.gov.my/economy/EID_web.htm〉.
[67] Mahlia TMI, Abdulmuin MZ, Alamsyah TMI, Mukhlishien D. An alternative energy source from palm wastes industry for Malaysia and Indonesia. Energy Conversion and Management 2001;42:2109–18.
[68] Duku MH, Gu S, Hagan EB. A comprehensive review of biomass resources and biofuels potential in Ghana. Renewable and Sustainable Energy Reviews 2011;15:404–15.
[69] Srisovanna P, Electricity supply industry in transitions: issues and prospect for Asia, in Thailand's Biomass Energy 2004.
[70] Loahalidanond K, Heil J, Wirtgen C. The production of sysnthetic diesel from biomass. Journal of KMITL Science Technology 2006;6(1):35–45.
[71] FOASTAT. 2011 April 15, 2011; Available from: 〈http://faostat.fao.org/site/567/DesktopDefault.aspx?PageID=567#ancor〉.
[72] Schoneveld GC, German LA, and Nutakor E, Paper summary—towards sustainable biofuel development: assessing the local impacts of large-scale foreign land acquisitions in Ghana. In: World Bank land governance conference 2010.
[73] Evans A, Strezov V, Evans TJ. Sustainability considerations for electricity generation from biomass. Renewable and Sustainable Energy Reviews 2010;14:1419–27.
[74] Statistics on commodities 2009, 2009, Ministry of Plantation Industries and Commodities: Malaysia.
[75] Yusof I, Farid NA, Zainal ZA, Azman M. Characterization of rice husk for cyclone gasifier. Journal of Applied Science 2008;8:622–8.
[76] Buku perangkaan pertanian, 2008, Kementerian Pertanian dan Industri Asas Tani: Malaysia.
[77] Northern corridor economic region, socioeconomic blueprint 2007–2025(2007), Malaysia: NCER.
[78] Official Portal of Agriculture Department. 2011 [cited 2011 Mach, 13]; Available from: 〈http://www.doa.gov.my/web/guest/data_perangkaan_tanaman〉.
[79] Karim Ghani Wan Ab, Firdaus Abdullah WA, Loung MS, Ho CJ, Matori KA. Characterization of vitrified Malaysia agrowaste ashes as potential recycling material. International Journal of Engineering and Technology 2008;5(2):111–7.
[80] Rosma A, Ooi KI. Production of Candida utilizes biomass and intracellular protein content: effect and agitation speed and aeration rate. Malaysia Journal of Microbiology 2006;2:15–8.
[81] Cheong MW, Supplementation of nitrogen sources and growth factors in pineapple waste extract medium for optimum yeast biomass production, 2009, University Science Malaysia: unpublished master thesis.
[82] Bhattacharya SC, Abdul Salam P, Runqing H, Somashekar HI, Racelis DA, Rathnasiri PG, Yingyuad R. An assessment of the potential for non-plantation biomass resources in selected Asian countries for 2010. Biomass and Bioenergy 2005;29:152–6.
[83] Abdullah M H. Characterization of solid and liquid pineapple waste. Reaktor 2008;12:48–52.
[84] Feasibility study on CDM project for pineapple waste to energy in Mindanoa Island Philippines, in Report of CDM/JI feasibility Studies2010, Global Environment Center Foundation.
[85] Monthly statistical bulletin Malaysia 2010, 2010Department of Statistics Malaysia.
[86] Bain RL, Overend RP, Craig KR. Biomass-fired power generation. Fuel Processing Technology 1998;54:1–16.
[87] Evans A, Strezov V, Evans TJ. Sustainability considerations for electricity generation from biomass. Renewable and Sustainable Energy Reviews 2010;14(5):1419–27.
[88] Biomass Energy Databook 2011, E.E.a.R.E. US Department of Energy, Editor 2011: US.
[89] Bridgwater AV, Toft AJ, Brammer JG. A techno-economic comparison of power production by biomass fast pyrolysis with gasification and combustion. Renewable and Sustainable Energy Reviews 2002;6:181–248.
[90] Strzalka R, Erhart TG, Eicker U. Analysis and optimization of cogeneration system based on biomass combustion. Applied Thermal Engineering 2011.
[91] Zhang L, Xu CC, Champagne P. Overview of recent advances in thermo-chemical conversion of biomass. Energy Conversion and Management 2010;51(5):969–82.
[92] McKendry P. Energy production from biomass (part 2): conversion technologies. Bioresource Technology 2002;83(1):47–54.
[93] IEA. Task 33; Thermal gasification facilities. [cited 2012 07.05]; Available from: 〈http://www.ieatask33.org/content/thermal_gasification_facilities〉.
[94] Balat M, et al. Main routes for the thermo-conversion of biomass into fuels and chemicals. Part 1: Pyrolysis systems. Energy Conversion and Management 2009;50(12):3147–57.
[95] Demirbas A. Partly chemical analysis of liquid fraction of flash pyrolysis products from biomass in the presence of sodium carbonate. Energy Conversion Management 2002;43:1801–9.
[96] Carneiro P, Ferreira P. The economic, environmental and strategic value of biomass. Renewable Energy 2012;44:17–22.
[97] Wu CZ, et al. An economic analysis of biomass gasification and power generation in China. Bioresource Technology 2002;83:65–70.
[98] Kumar A, Cameron JB, Flynn PC. Biomass power cost and optimum plant size in Western Canada. Biomass and Bioenergy 2003;24:445–64.
[99] Nouni MR, Mullick SC, Kandpal TC. Biomass gasifier projects for decentralized power supply in India: a financial evaluation. Energy Policy 2007;35:1373–85.
[100] Dwivedi P, Alavalapati JRR. Economic feasibility of electricity production from energy plantations present on community-managed forestlands in Madhya Pradesh, India. Energy Policy 2009;37:352–60.
[101] Kumar A, et al. Optimization and economic evaluation of industrial gas production and combined heat and power generation from gasification corn stover and distillers grains. Bioresource Technology 2010;101:3696–701.
[102] Delivand MK, et al. Economic feasibility assessment of rice straw utilization for electricity generating through combustion in Thailand. Applied Energy 2011;88:3651–8.
[103] Rendeiro G, et al. Analysis on the feasibility of biomass power plants adding to the electric power system-economic, regulatory and market aspects-state of Para, Brazil. Renewable Energy 2011;36:1678–84.
[104] Yagi K, Nakata T. Economic analysis on small scale forest biomass gasification considering geographical resources distribution and technical characteristics. Biomass and Bioenergy 2011;35:2883–92.
[105] Dassanayake GDM and A Kumar, Techno-economic assessment of triticale straw for power generation, Applied Energy 2012.
[106] Upadhyay TP, et al. Economic feasibility of biomass gasification for power generation in three selected communities of northwestern Ontario Canada. Energy Policy 2012;44:235–44.
[107] Yoshida Y, et al. Comprehensive comparison of efficiency and CO_2 emissions between biomass energy conversion technologies-position of supercritical water gasification in biomass technologies. Biomass and Bioenergy 2003;25:257–72.
[108] Coronado CR, Yoshioka JT, Silveira JL. Electricity, hot water and cold water production from biomass. Energetic and economical analysis of the compact system of cogeneration run with woodgas from a small downdraft gasifier. Renewable Energy 2011;36(6):1861–8.
[109] Dornburg V, Faaij APC. Efficiency and economic of wood- fired biomass energy system in relation to scale regarding heat and power generation using combustion and gasification technologies. Biomass and Bioenergy 2001;21:91–108.
[110] Jaafar MZ, Kheng WH, Kamaruddin N. Greener energy solutions for a sustainable future:issues and challenges for Malaysia. Energy Policy 2003;31:1061–72.

[111] Mohamed AR, Lee KT. Energy for sustainable development in Malaysia: energy policy and alternative energy. Energy Policy 2006;34:2388–97.
[112] Ali R, Daut I, Taib S. A review on existing and future eneryg sources for electrical power generation in Malaysia. Renewable and Sustainable Energy Reviews 2012;16:4047–55.
[113] Kalinci Y, Hepbasli A, Dincer I. Comparative exergetic performance analysis of hydrogen production from palm oil wastes and some other biomasses. International Journal of Hydrogen Energy 2011;36:11399–407.
[114] Tsamba AJ, Yang W, Blasiak W. Pyrolysis characteristics and global kinetics of coconut and cashew nut shells. Fuel Processing Technology 2006;87(6): 523–30.
[115] Parikh J, Channiwala SA, Ghosal GK. A correlation for calculating HHV from proximate analysis of solid fuels. Fuel 2005;84(5):487–94.
[116] Jorapur R, Rajvanshi AK. Sugarcane leaf-bagasse gasifiers for industries heating application. Biomass and Bioenergy 1997;13(3):141–6.
[117] H LV. Australia.University of Southern Quesland; 2004 Cofiring of rice husk for electricity generation in Malaysia, in Engineering Mechanical.
[118] Calvo LV, et al. Heating process characteristics and kinetics of rice straw in different atmospheres. Fuel Processing Technology 2004;85(4):279–91.
[119] Qin X, et al. Switchgrass as an alternative feedstock for power generation: integrated environment, energy and economic life cycle assessment. Journal of Clean Technologies and Environmental Policy 2006;8:233–49.
[120] Husain Z, Zainal ZA, Abdullah MZ. Analysis of biomass-residue-based cogeneration system in plam oil mills. Biomass and Bioenergy 2003;24: 117–24.
[121] Singh SP, Singh D. Biodiesel production through the use of different sources and characterization of oils and their esters as the substitute of diesel: a review. Renewable and Sustainable Energy Reviews 2010;14(1):200–16.
[122] Yusuf NNAN, Kamarudin SK, Yaakub Z. Overview on the current trends in biodiesel production. Energy Conversion and Management 2011;52(7): 2741–51.
[123] Lin L, et al. Opportunities and challenges for biodiesel fuel. Applied Energy 2011;88(4):1020–31.
[124] Ong HC, T.M.I M, Masjuki HH. A review on energy pattern and policy for transportation sector in Malaysia. Renewable and Sustainable Energy Reviews 2012;16(1):532–42.
[125] Sulaiman F, et al. An outlook of Malaysian energy, oil palm industry and its utilization of wastes as useful resources. Biomass and Bioenergy 2011;35(9):3775–86.
[126] Kalinci Y, Hepbasli A, Dincer I. Biomass-based hydrogen production: a review and analysis. International Journal of Hydrogen Energy 2009;34(21): 8799–817.
[127] Kirtay E. Recent advances in production of hydrogen from biomass. Energy Conversion and Management 2011;52(4):1778–89.
[128] Balat H, Kirtay E. Hydrogen from biomass—present scenario and future prospects. International Journal of Hydrogen Energy 2010;35(14):7416–26.
[129] Mohammed MAA, et al. Air gasification of empty fruit bunch for hydrogen-rich gas production in a fluidized-bed reactor. Energy Conversion and Management 2011;52(2):1555–61.